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A review on the development of wind energy in Turkey

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Abstract

Achieving sustainable development is a target that is now widely seen as important to worldwide public opinion. In this regard, the utilization of renewable energy resources, such as solar, geothermal, and wind energy, appears to be one of the most efficient and effective ways in achieving this target. Recently, wind power as a potential energy has grown at an impressive rate in Turkey.

This paper reviews the development of wind energy in the country as of the end of October 2003, including its history, studies conducted on wind energy, restructuring of the Turkish electricity market and wind energy applications.

Turkey's total theoretically available potential for wind power may be around 88,000 MW annually, with particularly attractive areas for wind located along Turkey's west coast and in southeastern Anatolia. Electricity generation through wind energy for general use was first realized in Izmir, Turkey in 1986 with a 55 kW nominal wind energy capacity. However, the utilization of wind energy in Turkey has increased since 1998 when the first wind power plant with a total capacity of 1.5 MW was installed. Up to date, three wind power plants were installed with a total capacity of 18.9 MW, while a wind power plant with a total capacity of 1.2 MW will be commissioned in November 2003.

Present applications have shown that wind energy in Turkey is a promising alternative and the strong development of wind energy is expected to continue in the coming years following restructuring of the Turkish electricity market.

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Contents

1. Introduction

The demand for energy is increasing at an exponential rate due to the exponential growth of world population. The combined effect of the widespread depletion of fossil fuels and the gradually emerging consciousness about environmental degradation has given priority to the use of conventional and renewable alternative energy sources such as solar, wind and solar-hydrogen energies [1]. The rapid development in wind energy technology has made it an alternative to conventional energy systems in recent years. Parallel to this development, wind energy systems have made a significant contribution to daily life in developing countries, where one-third of the world's people live without electricity [2,3].

Most developed countries are facing many challenges as they prepare to meet their energy needs during the 21st century and develop many programs, which support the use and deployment of renewable energy sources. For example, the US Department of Energy's (DOE's) Wind Energy Program recently began charting new directions for its efforts as follows: (i) Increasing the viability of wind energy by developing new cost-effective technology for deployment in less-energetic, developing cost-effective distributed, small-scale wind technology; and laying the groundwork for future work to tailor wind turbine technology to the production of hydrogen, and (ii) Increasing the deployment of wind energy by providing supporting research in power systems integration, resource information, market acceptance, and industry support [4].

The dawn of research and development (R&D) for using wind energy to generate electricity was technologically driven. Later, when the technology became more mature, other topics emerged such as those related to noise from wind energy systems, integration of wind generators into utility systems, public attitudes towards wind development, and the impact of wind developments on the environment. The benefits of past R&D in the wind energy sector have been clearly demonstrated by the increasing sizes of turbines and the lower prices per installed production capacity of electricity. Today, wind energy is cost-competitive with other forms of electrical generation at locations with a good wind resource. Thanks in large part to successful R&D, the wind energy market is in a state of rapid development. A number of growth studies have been presented about wind energy [5]. The power produced by wind turbines of the future will compete head to head on a cost of energy basis with coal and natural gas [4].

The cumulative installed capacity of wind energy worldwide as of the end of 1996, 1999 and 2002 is illustrated in Fig. 1, while world market growth rates between 1997 and 2002 are given in Table 1 [6]. As can be seen from this table, about 32,037 MW of capacity was installed worldwide in 2002, with an average of 35.7% installed over the last 5 years. Europe consolidated its leading position, accounting for 85.3% of all new installations in 2002. The US market fell back to a quarter of its peak in 2001. Asia demonstrated a steady development. A major share of new installation took place in Europe, with 85.4% of the total. Germany alone accounted for 53% of the European total, while development in Asia was slightly lower than in 2001. The top 10 markets in the world are headed by Germany, Spain, Denmark and the USA. Newcomers to the top 10 were Australia and The Netherlands. The US market fell back from its peak level of 1635 MW in 2001 to a modest 429 MW in 2002. Penetration of wind power in the world's electricity supply had reached 0.4% by the end of 2002 [7]. Wind energy projections made by some institutions and organizations, such as International Energy

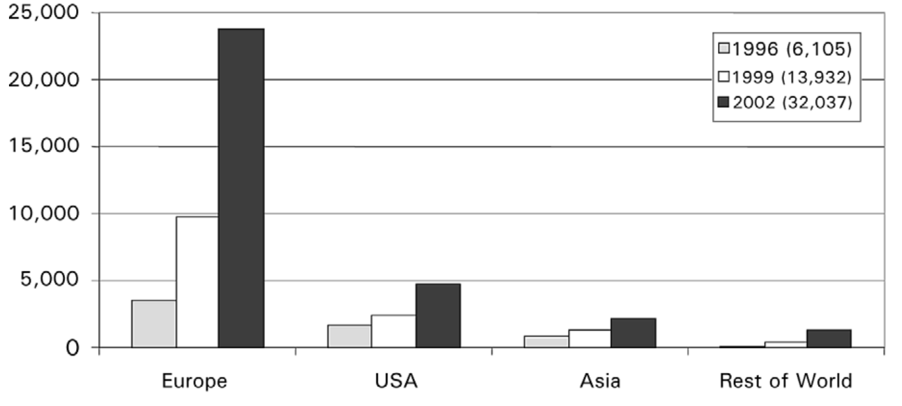

Fig. 1. The cumulative installed capacity of wind energy worldwide as of the end of 1996, 1999 and 2002 in MW [6].

Table 1
World market growth rates between 1997 and 2002 [6]

Year	Installed (MW)	Increase (%)	Cumulative (MW)	Increase (%)
1997	1568		7636	
1998	2597	66	10,153	33
1999	3922	51	13,932	37
2000	4495	15	18,449	32
2001	6824	52	24,927	35
2002	7227	6	32,037	29
Average growth of 5 years		35.7		33.2

Agency, European Commission and BTM Consult ApS, differ from each other, as given in detail elsewhere [5]. These projections are based on the studies performed between 1997 and 2000. According to a forecast of 2003 made by BTM Consult ApS for the period up to 2007, an average growth rate of 11.2% yearly is projected, while for 2003 a growth of 24% over 2001 is expected. Total demand during the 5 year period is estimated to be 51,000 MW. By the end of 2007, 83,000 MW of capacity will be on line, of which 58,600 MW is in Europe. According to long term prediction up to 2012, an annual installation level of 24,000 MW by 2012 is expected. Cumulative installation growth to 177,000 MW is projected to equal a penetration of wind power close to 2% of the world's electricity consumption by 2012 [7].

The European Commission in its White Paper on Renewable Sources of Energy has set the goal of achieving a 12% penetration of renewables in the European Union (EU) by 2010. One of the targets of the White Paper is to increase the EU electricity production from renewable energy sources from 337 TW h in 1995 to 675 TW h in 2010. Within this target the goal for wind energy is 40,000 MW of installed capacity in 2010, which could produce 80 TW h of electricity and save 72 Mt of CO_2 per year [8].

The structure of the paper is as follows: The first section includes the introductory part; Section 2 describes the historical development of wind energy worldwide and in Turkey; studies conducted on wind energy related subjects in Turkey are treated in the third section, while Section 4 gives history of the Turkish electricity market; Turkey wind atlas, and potential and applications of wind energy in the country are presented in Sections 5 and 6, respectively; and the last section concludes.

2. Historical development of wind energy

The wind has played a long and important role in the history of human civilization. Wind power has been harnessed by mankind for thousands of years. Since earliest recorded history, wind power has been used to move ships, grind grain and pump water. There is evidence that wind energy was used to propel boats along the Nile River as early as 5000 B.C. The first true windmill, a machine with vanes

attached to an axis to produce circular motion, may have been built as early as 2000 B.C. in ancient Babylon. By the 10th century A.D., windmills with wind-catching surfaces as long as 16 feet and as high as 30 feet were grinding grain in the area now known as eastern Iran and Afghanistan [9–12].

The western world discovered the windmill much later. The earliest written references to working wind machines date from the 12th century. These were used for milling grain. It was not until a few 100 years later that windmills were modified to pump water and reclaim much of Holland from the sea [10]. The first horizontal-axis windmill appeared in England around 1150, in France 1180, in Flanders 1190, in Germany 1222 and in Denmark 1259. This fast development was most likely influenced by the Crusaders, taking the knowledge about windmills from Persia to many places in Europe [12]. The people of Holland improved the basic design of the windmill. They gave it propeller-type blades made of fabric sails and invented ways for it to change direction so that it could continually face the wind. Windmills helped Holland become one of the world's most industrialized countries by the 17th century [13]. The first person, who generated in 1891 electricity from wind speed, was the Dane Poul LaCour, who lived in Denmark. He had also received meteorology education and used the wind tunnel for the first time in order to obtain some theoretical formulations. Danish engineers improved the technology during World Wars I and II and used the technology to overcome energy shortages [13,14].

In Europe, windmill performance was constantly improved between the 12th and 19th centuries. By 1800, about 20,000 modern European windmills were in operation in France alone. And in the Netherlands, 90% of the power used in industry was based on wind energy. Industrialization then led to a gradual decline in windmills, but even in 1904 wind energy provided 11% of the Dutch industry energy and Germany had more than 18,000 units installed [12].

American colonists used windmills to grind wheat and corn, pump water, and cut wood. As late as the 1920s, Americans used small windmills to generate electricity in rural areas without electric service. When power lines began to transport electricity to rural areas in the 1930s, local windmills were used less and less, though they can still be seen on some Western ranches [13]. The popularity of windmills in the US reached its peak between 1920 and 1930 with about 600,000 units installed. Various types of American windmills are still used for agricultural purposes all over the world [12].

In the 1930s and 1940s, hundreds of thousands of electricity producing wind turbines were built in the US. They had two or three thin blades, which rotated at high speeds to drive electrical generators. These wind turbines provided electricity to farms beyond the reach of power lines and were typically used to charge storage batteries, operate radio receivers and power a light bulb or two. By the early 1950s, however, the extension of the central power grid to nearly every American household, via the Rural Electrification Administration, eliminated the market for these machines [15].

The popularity of using the energy in the wind has always fluctuated with the price of fossil fuels. When fuel prices fell after World War II, interest in wind

turbines waned. But when the price of oil skyrocketed in the 1970s, so did world-wide interest in wind turbine generators. The wind turbine technology R&D that followed the oil embargoes of the 1970s refined old ideas and introduced new ways of converting wind energy into useful power. Many of these approaches have been demonstrated in ‘‘wind farms’’ or wind power plants-groups of turbines that feed electricity into the utility grid-in the US and Europe [16]. The wind technology was improved step by step since the early 1970s. By the end of the 1990s, wind energy has re-emerged as one of the most important sustainable energy resources [12].

Today, the lessons learned from more than a decade of operating wind power plants, along with continuing R&D, have made wind-generated electricity very close in cost to the power from conventional utility generation in some locations [16].

As for the background in Turkey, wind energy has always played an important role in the historical and economical development of Asia Minor and the geographical area covered by the Republic of Turkey today. The earliest documented evidence of this statement goes back to the ancient city of Troia. It is not known when the first windmills were installed in Anatolia. However, they must have been dominant landmarks already in the 14th century. A naval map dated 1389 AC shows windmills as landmarks along with the shallows and sand banks in the Bay of Izmir [17,18].

In 1940’s windmills ground corn, pumped water to fields and even powered the first radio sets at the Anatolia countryside. Based a survey performed by the Turkish Ministry of Agriculture between 1960 and 1961, there were 749 windmills. Of these, 718 were used for water pumping, while 41 were for generating electricity. Two surveys between 1966–1967 and 1978–1979 revealed 309 and 894 units, of which 2 and 23 were electricity producing turbines with capacities lower than 1 kW, respectively [17].

Since the 1960s, several universities have conducted studies on wind energy [19]. The Turkish Scientific and Technologic Research Institution (TUBITAK) Marmara Research Center has started with studies towards developing a wind atlas for Turkey since the 1980’s. The General Directorate of Electrical Power Resources Survey Administration (EIE) has made some wind measurements [17].

Electricity generation through wind energy for general use was first realized at Cesme Altinyunus Resort Hotel (The Golden Dolphin Hotel) in Izmir, Turkey in 1986 with a 55 kW nominal wind power capacity [20]. This hotel with 1000 beds consumes of about 3 million kW h of electrical energy annually, while the windmill installed produces 130,000 kW h per year approximately [21]. Between 1986 and 1996, there were some attempts to generate electricity from wind, but they were never successful [22]. In 1994, the first Build-Operate-Transfer (BOT) feasibility study for a wind energy project in Turkey was presented to the Ministry of Energy and Natural Resources of Turkey (MENR) [23]. Apart from initial high investment costs in harnessing wind energy, lack of adequate knowledge on the wind speed characteristics in the country is the main reason for the failure to harvest the energy from wind. In terms of generating electricity from wind, the development of wind energy in Turkey started in 1998 when some wind plants were installed at

several locations in the country. By January 1998, there were 25 applications for wind energy projects recorded at the MENR. Up to date, three wind power plants were installed with a total capacity of about 18.9 MW [23,24]. Considering the installation of a wind plant with a capacity of 1.2 MW in November 2003, total installed capacity will reach 20.1 MW [25]. Recently, small wind turbine systems with capacities ranging from 1.5 to 5 kW have also been installed in some Turkish universities for conducting wind energy investigations as well as for lighting purposes [26].

3. Studies conducted on wind energy related subjects in Turkey

The studies conducted on wind energy related subjects in Turkey may be summarized as follows: (a) the studies performed on the base of Science Citation Index (SCI) publications, which are shortly called the SCI studies and limited to the years between 1994 and 2003, and (b) undergraduate studies (UGs). In Turkey, during the last 3–4 years, the number of wind energy related conferences and symposiums as well as meetings has also significantly increased. Papers presented and published in these scientific activities are not included in this classification.

3.1. SCI studies

These studies may be classified in five groups as follows: (i) wind energy potential [14,27–32], as given in detail below, (ii) wind speed analyses and wind speed distribution functions [33–39], (iii) wind power assessments [40–42], (iv) solar-wind hybrid systems [43], and (v) some other studies including status, potential, utilization and future perspectives of wind energy as well as a brief review among the renewable energy sources [17,19,21,44–50].

The SCI studies have been mostly concentrated on the determination of wind energy potential. The Turkish State Meteorological Service (TSMS), founded in 1937, is the only legal organization in Turkey to provide all meteorological data and information [51]. The 1970–1980 records of the measurement stations belonging to the TSMS were evaluated by the EIE, and the distribution of wind energy throughout the country was given. Bandirma, Antakya, Kumkoy, Mardin, Sinop, Gokceada, Corlu and Canakkale were determined as very abundant zones in terms of wind energy potential [52]. The EIE has conducted studies towards the measurement of wind speeds and directions since 1990 at the selected locations having high wind potential [53]. In addition to this, local assessments of wind energy potential were made in other zones, such as Akhisar [14], Gokceada [27], Bozcaada [28,29], Nurdagi-Gaziantep [30] and Turkey's regions [31,32].

3.2. Undergraduate studies (UGs)

In Turkey, a database system related to UGs completed has been constituted by the National Academic Network and Information Center (ULAKBIM), established in 1987 in Ankara, Turkey [54]. The data on UGs were collected from this

Table 2
Studies conducted on wind energy related subjects in Turkey at the undergraduate level between 1991 and 2002

Item No.	Classification of wind energy related theses according to their subject matters	Number of M.Sc. theses	Number of Ph.D. theses
1	Experimental	13	–
2	Modeling	7	5
3	Wind energy potential and atlas	21	–
4	System and technology design (including turbine, blade etc.)	15	–
5	Application in agriculture	3	–
6	Environmental effects	8	1
7	Cost analysis	4	–
8	Aerodynamic	2	–
9	Hybrid	2	–
10	Law	1	–
11	Wind tunnel	10	–
12	Investigation of wind energy plants	4	–
13	Others	13	3
	Total	103	9

center in order to classify them, as shown in Table 2. It is clear from this table that total number of UGs completed between 1991 and 2002 amounts to 112. Of this, nine are related to Ph.D. theses, while the remainder belongs to M.Sc. theses.

4. History of the Turkish electricity market

The Turkish electricity industry dates back to 1902, when a 2 kW dynamo was connected to a water mill in Tarsus. The first larger-scale power plant was built in Istanbul in 1913. In 1935, several government institutions with authority relating to electricity production were established. These included the Electric Power Resources Survey and Development Administration (Elektrik Isleri Etut Idaresi, EIEI), which still exists today. EIEI carries out surveys and preparatory work to identify hydro potential, and plans and prepares dam and hydro plant projects. EIEI is also involved in studying energy conservation and the use of new and renewable energy resources [55].

Up to 1971, the power plants were operated by some governmental organizations and institutions established with a special law. According to a law issued in 1971, Turkish Electricity Authority (called in Turkish TEK) was responsible as a whole for the generation and distribution of electricity throughout the country. Although the wind of the privatization studies has blown since 1984, the private sector was not so much active on this matter until 1985 because the details of the privatization were not examined in the first law issued [56,57]. Law no. 3096, named “Respecting Authorization to Institutions other than the TEK for Generation, Transmission, Distribution and Trade of Electricity”, issued in 1984, allowed

the private sectors to build and operate the electricity generation, transmission and distribution systems for the first time in the history of Turkish Republic. On the other hand, in order to provide financial support to power projects and to maintain stability of electrical energy prices, electrical energy fund (EEF) was established in March 1990, by law no. 3613. The regulation relating to the application of EEF law was put into effect in 1991 [58].

TEK had been included in the scope of privatization studies in 1993. In February 2001, Turkey passed the long-anticipated Electricity Market Law, which paves the way for a free market in power generation and distribution in the country. Among other things, the legislation calls for: (1) TEAS (the Turkish Electricity Generation and Transmission Corporation) to be broken up into separate generation, distribution, and trade companies; (2) trade and generation companies to be privatized, while transmission remains in state hands; and (3) a new regulatory board to be set up which will oversee the Turkish power market, set tariffs, issue licenses, and prevent uncompetitive practices. The new law throws into doubt the fate of dozens of BOT and TOR (transfer-of-operating-rights) power projects [59].

Restructuring of the electricity sector in Turkey has started with the establishment of the Energy Market Regulatory Authority (EMRA), which was commissioned on November 19, 2001. In May 2002, the EMRA issued drafts of the Energy Market Licensing Regulation and the Electricity Market Tariffs Regulation, and these regulations went into effect in August 2002. The EMRA has announced a four-stage approach to a competitive electricity market. The first stage grants licenses to firms in the electricity and natural gas markets, while the second stage, which is expected to start March 3, 2003, will give large industrial users the right to choose their electricity provider. The third stage will start to set up the Market Financial Reconciliation Center for balancing and settlements, and the fourth stage will make this Center fully operational. Legislation has been proposed in the Turkish parliament that would expand the scope of the EMRA to include the upstream activities in the petroleum market. This Petroleum Market Bill is expected to be considered by the parliament in the near term [60].

In the framework of restructuring Turkish electricity sector, comprehensive and detailed studies to determine the basic parameters of the sector have been implemented by the MENR and the consultants. The main goal of these studies is to establish an institutional structure and the corresponding regulatory framework for the sector. According to the MENR, besides the installed capacity up to 2020, major infrastructure projects would also require investments of US$ 3–5 billion per year in terms of the investments in transmission and distribution systems. This could lead to building a total installed generating capacity of as much as 65,000 MW_e by 2010. Much of them would need to come from the private sector. Thus, the MENR has conceived some options for financing projects [57,60]. In this regard, Turkey implemented new methods for energy project financing and ownership. Five models were offered: (a) build, operate and transfer (BOT), (b) build, own operate (BO or BOO), (c) autoproduction, (d) transfer of operating rights (TOR or TOOR) and (e) conventional tendering system by TEAS, as described in detail by Hepbasli and Ozalp [57,61].

Turkey's electricity sector has grown rapidly from 32.8 MW with the foundation of the Republic of Turkey in 1923 to 27.26 GW. The MENR has planned for a very large increase in electric generating capacity over the next 20 years. According to forecasts prepared by the MENR, the country will need about an electric power capacity of 65 GW by 2010, and about 105 GW by 2020. Electric energy generation capacity is expected to have to rise from about 117 TW h in 2001 to more than 347 TW h and 624 TW h in 2010 and 2020, respectively. This implies power demand growth rates of at least 8% per annum for the coming decade and at least 6% per annum for the following decade [55,60]. At present, not only the electricity sector, the whole energy sector in Turkey is in a dynamic change.

5. Turkey wind atlas

It is significant to have information about availability of local wind power in order to make use of wind power for generating electricity and to determine the amount of energy to be produced. Wind atlas, prepared to display areas potentially suitable for energy production from wind energy, describes statistical data on regional mean wind speeds and power densities [62,63].

Dundar et al. [62,63] have made onsite surveys at 96 meteorological stations distributed homogeneously over Turkey. They evaluated the data gained from 45 stations for the preparation of the Turkey Wind Atlas and drawn the atlas using well-known WASP (Wind Atlas Analysis and Application Program) model used for the European Wind Atlas. The Turkey Wind Atlas is illustrated in Fig. 2, which includes power potentials at a height of 50 m above the ground level for five various windy regimes given in Table 3 [62,63]. Geographical coordinates and measurement periods of the 45 measurement stations designated in Fig. 2 are presented in detail elsewhere [64].

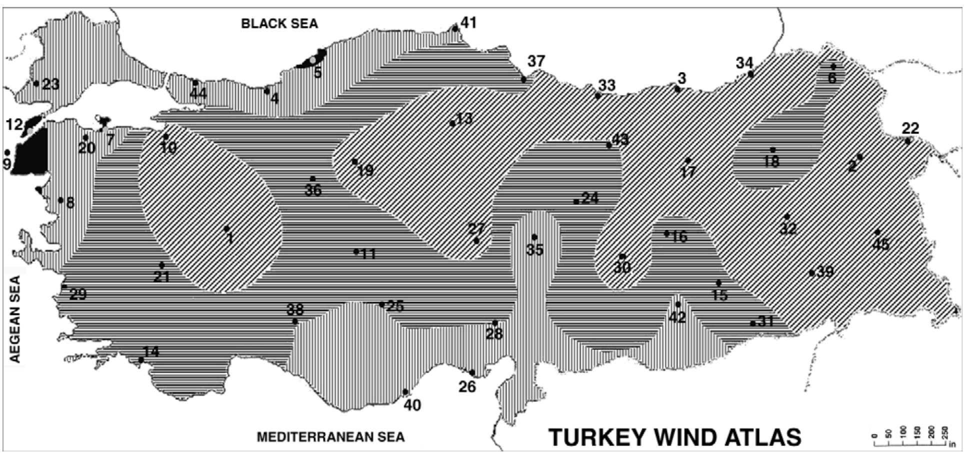

Fig. 2. Turkey wind atlas [62–64].

Table 3
Power potentials at a height of 50 m above the ground level for five various windy regimes indicated in the Turkey Wind Atlas[a] [62,63]

Symbol	Unopened area[b]		Open area[c]		Sea shore[d]		Sea surface[e]		Hills and slopes[f]	
	m/s	W/m^2	m/s	W/m^2	m/s	W/m^2	m/s	W/m^2	m/s	W/m^2
	>8.0	>250	>7.5	>500	>8.5	>700	>9.0	>800	>11.5	>1800
	5.0–6.0	150–250	6.5–7.5	300–500	7.0–8.5	400–700	8.0–9.0	600–800	10.0–11.5	1200–1800
	4.5–5.0	100–150	5.5–6.5	200–300	6.0–7.0	250–400	7.0–8.0	400–600	8.5–10.0	700–1200
	3.5–4.5	50–100	4.5–5.5	100–200	5.0–6.0	150–250	5.5–7.0	200–400	7.0–8.5	400–700
	<3.5	<50	<4.5	<100	<5.0	<150	<5.5	<200	<7.0	<400

[a] Wind potential represents the wind power. Wind turbines may utilize between 20% and 30% of the available potential. The mean air density at sea level is taken to be 1.23 kg/m^3 at a temperature of 15 °C.
[b] Agricultural fields concentrated with settlements, forests and wind barriers (roughness class 3).
[c] Open areas having a little amount of wind barriers (roughness class 1).
[d] Smooth sea shores and shores including wind barriers in a very little amount.
[e] Sea surfaces with a distance of minimal 10 km from shores (roughness class 0).
[f] It has been obtained from the calculations based on a symmetrical hill with a height of 400 m and a diameter of 4 km. The increase in wind velocity depends on the height, length and structure of the hill.

6. Potential and applications of wind energy in Turkey

Turkey has substantial reserves of renewable energy sources. Renewable energy production represented about 14.4% of TPES, i.e. 10.10 million tons of oil equivalent (Mtoe) in 1999, and renewables are the second-largest domestic energy source after coal. Slightly less than two-thirds of this production is supplied by biomass and animal waste; another third is supplied by hydropower and about 0.5% of the total is produced from geothermal, wind and solar sources [55].

Turkey has major potential for energy efficiency improvements. Exploitation of this potential could reduce environmental emissions and improve security of supply. The potential for renewables is also significant. In recent years, progress has been made in both fields. New energy efficiency legislation and regulations are under preparation that will go some way towards using this potential. Turkey now has a clear target for wind generation, and numerous wind projects were submitted under the BOT program in recent years [55].

Turkey has a land surface area of officially 774,815 km^2. It is surrounded by the Black Sea in the North, the Marmara and the Aegean Sea on the West and the Mediterranean Sea in the South, giving it very long seashores. All the land area of Turkey is not suitable for the installation of turbines due to a topographic structure. Based on the examination of the wind atlas given in Fig. 2 may be concluded that the regions of Aegean, Marmara and East-Mediterranean have high wind energy potential. Turkey's total theoretically available potential for wind power is calculated to be around 88,000 MW annually. More than 98% of the wind energy potential is concentrated in regions 3 and 4 [52,64]. It is also estimated that Turkey has an economical wind power potential of about 10,000 MW_e [60].

Progress in wind energy technology in recent years has drawn private-sector attention to this energy resource. As a consequence, numerous companies have submitted their applications to the MENR for the construction of new wind power plants [55]. Figs. 3 and 4 show an history of Turkey's wind energy installations by capacities and Turkey's map indicating the locations of current wind power plants, respectively, while the distribution of wind energy plants installed as of October 2003 is illustrated in Table 4 [22,25]. The first wind power plant with a total installed capacity of 1.5 MW, excepting to the small wind system with a capacity of 55 kW, was commissioned in February 1998. Wind power production is not very large, but total installed capacity has reached 18.9 MW and will increase to 20.1 MW with an additional power plant to be commissioned in November 2003 [25]. Besides this, 72 new projects totaling about 2000 MW are under evaluation by the MENR. The goal is for wind power to represent about 2% of installed electric power capacity in 2005 [55,65].

As for the distribution of electricity production by sources in Turkey, it may be said that thermal and hydroelectric plants generated about 80% of Turkey's electricity in 2001, as can be seen in Table 5 [66]. It is clear from this table that the share of electricity produced from wind power in total is very low, representing 0.05% of the total with a capacity of 57 GW h in the same year. It may also be concluded that Turkey is a net importer of electricity. However, compared to total

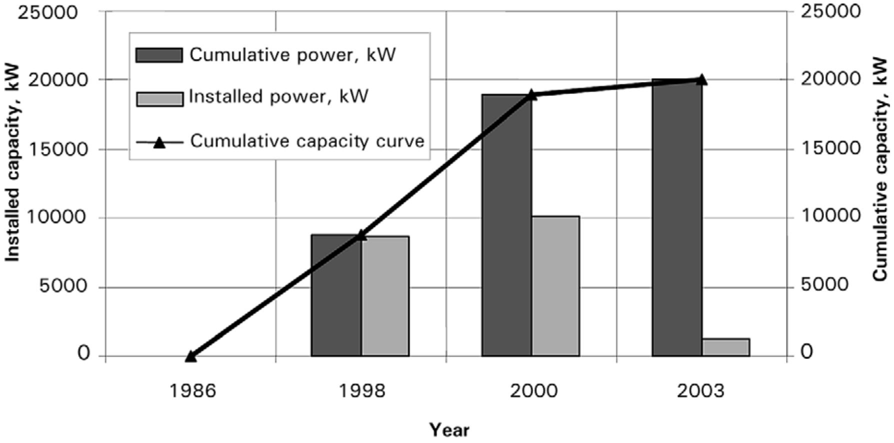

Fig. 3. History of Turkey's wind energy installations by capacities during 1986–2003 [22,25].

power supply levels, Turkey's power imports are insignificant, with a value of about 3.6% in 2001.

7. Conclusions

In the past decade, wind energy has become a valuable and dependable source of electricity worldwide. As a renewable, domestic resource, wind energy is poised to become our least expensive form of bulk electricity generation. Although the

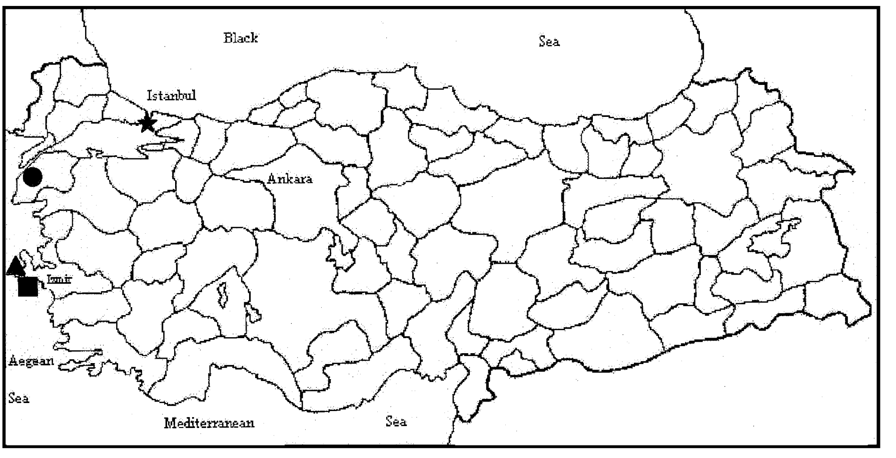

Fig. 4. Turkey's map indicating the locations of current wind power plants [22,25]. (■)Cesme—Alacati, (▲) Cesme—Germiyan, (●) Bozcaada, (★) Istanbul.

Table 4
Distribution of Turkey's wind energy installations by regional as of October 2003 [22,25]

Name of project	Place	Region	Commissioning date	Capacity of each turbine (kW)	Number of turbines	Installed capacity (MW)	Diameter of rotors (m)	Type of generator
Cesme Germiyan	Izmir—Cesme	Aegean	February 1998	500	3	1.5	40.3	Enercon-40
Cesme Alacati	Izmir—Cesme—Alacati	Aegean	November 1998	600	12	7.2	44	Vestas-V44
Bozcaada	Canakkale—Bozcaada	Marmara	25 July 2000	600	17	10.2	44	Enercon-40
Istanbul	Istanbul—Hadimkoy	Marmara	Under construction[a]	600	2	1.2	44	Enercon-40
Total					34	20.1		

[a] To be commissioned in November 2003.

Table 5
Distribution of Turkey's electricity production by utilities during 1990–2001 in GW h

Utilities	Energy resource	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
EUAS[a]	Thermal	30,618	33,987	36,867	35,294	42,919	38,353	31,600	35,062	38,895	42,583	46,095	46,970
	Hydro	22,156	21,393	24,597	31,728	28,945	33,105	37,440	37,342	39,601	31,737	27,772	20,409
	Geothermal	80	81	70	78	79	86	84	83	85	81	76	90
	Total	52,854	55,461	61,533	67,100	71,943	71,544	69,124	72,487	78,581	74,401	73,942	67,469
Concessionary companies	Thermal	346	131	123	329	123	0	0	0	0	0	0	0
	Hydro	959	1239	1892	2,138	1563	2301	2908	2214	2299	2169	1903	1346
	Total	1305	1370	2015	2,467	1686	2301	2908	2214	2999	2169	1903	1346
Autoproducers[b]	Thermal	3351	3365	3715	4,156	4615	5617	6061	7745	10,097	12,493	15,895	17,797
	Hydro	10	4	12	16	4	8	10	9	31	32	63	112
	Geothermal	–	–	–	–	–	–	–	–	4	4	4	4
	Total	3361	3369	3727	4,172	4619	5625	6071	7754	10,132	12,529	15,962	17,914
Production companies	Thermal	–	–	–	–	–	–	351	2157	2217	8469	10,936	11,151
	Hydro	23	47	67	69	74	126	118	252	298	739	1073	2071
	Wind	–	–	–	–	–	–	–	–	2	16	29	57
	Total	23	47	67	69	74	126	469	2409	2517	9224	12,039	13,279
Affiliated partnerships of TEAS[c]	Thermal	–	–	–	–	–	6651	16,291	18,432	17,494	17,911	19,292	18,894
Mobil power plant	Thermal	–	–	–	–	–	–	–	–	–	205	644	1117
Transfer of operating rights	Thermal	–	–	–	–	–	–	–	–	–	–	1073	2634
	Hydro	–	–	–	–	–	–	–	–	–	–	68	73
	Total	–	–	–	–	–	–	–	–	–	–	1141	2707
Turkey production	Thermal	34,315	37,482	40,705	39,779	47,657	50,621	54,303	63,397	68,703	81,661	93,934	98,563
	Hydro	23,148	22,683	26,568	33,951	30,586	35,541	40,475	39,816	42,229	34,678	30,879	24,010
	Geothermal +wind	80	81	70	78	79	86	84	83	91	101	109	152
	Total	57,543	60,246	67,342	73,808	78,322	86,248	94,862	103,296	111,023	116,440	124,922	122,725

(continued on next page)

Table 5 (*continued*)

Utilities	Energy resource	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Import	Bulgaria	0	568	–	–	–	–	26	1863	2317	1798	3297	3776
	SSCB	54	–	–	–	–	–	–	–	–	–	–	–
	Georgia	122	191	189	13	31	–	16	459	779	239	205	523
	Iran	–	–	–	–	–	–	55	170	202	292	290	281
	Azerbaijan	–	–	–	200	–	–	174	0	0	0	0	0
	Total	176	759	189	213	31	–	270	2492	3299	2330	3791	4579
Export		907	506	314	589	570	696	343	271	298	285	437	433
Turkey consumption		56,812	60,499	67,217	73,432	77,783	85,552	94,789	105,517	114,023	118,485	128,276	126,871

[a] With the sole purpose of carrying out electricity services, EUAS (Electricity Generation Incorporated Company) has been founded by the cabinet's decree dated February 5, 2001 no. 2001/2026 and active since October 1, 2001.

[b] The production of electricity by industrial facilities for their own use in Turkey based on the Turkish Trade Law is called autoproduction.

[c] On 3 March 2000, the Council of Ministers issued a Decree (Law No. 310) that provides for TEAS (the Turkish Electricity Generation and Transmission Corporation) to be split into three separate companies.

promise of wind energy is immense, continued industry growth rests heavily on sustaining aggressive research, development, and support programs [67].

Turkey has a considerably high level of renewable energy resources that can be utilized to satisfy a part of the total energy demand in the country. Present applications have shown that renewable energy sources in Turkey are a promising alternative.

The main conclusions drawn from the present study can be summarized as follows:

(a) Aegean, Marmara, and East-Mediterranean regions of Turkey are generally seen as promising of higher wind power potential compared to other parts of Turkey.
(b) Turkey's total theoretically available potential for wind power is estimated to be around 88,000 MW.
(c) Turkey will have 20.1 MW of wind power installed capacity by the end of November 2003, up from the current national capacity of 18.9 MW obtained from three wind power plants.
(d) Electricity produced from wind energy between 1998 and 2001 in Turkey amounts to 104 GW h.
(e) The MENR has planned for a very large increase in electric generating capacity over the next 20 years. Up to the end of 2020, an additional capacity of approximately 78 GW is required in order to meet the increasing demand of the country. As a result, wind farm generation can contribute significantly to national energy needs by feeding directly into the existing electricity networks in Turkey.
(f) New financing mechanisms are needed to promote investment in energy efficiency and renewable energy, which will support the development of wind energy systems in Turkey [22].
(g) The strong development of wind energy in Turkey is expected to continue in the coming years.

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